Soil Moisture and Crop Production

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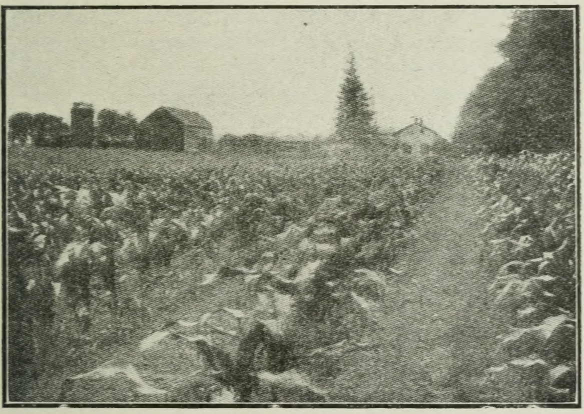

Fig. 52.—*Corn growing in a soil covered by an excellent dust mulch.*

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SOIL MOISTURE AND CROP PRODUCTION

Elmer O. Fippin

The large use of water by plants and its derivation from the soil are facts commonly understood. The object of this lesson is to point out the extent to which plants use water and the manner of its use, and to explain the ways in which water is collected and conserved in the soil for this purpose.

USES OF WATER BY PLANTS

The water used by plants serves many purposes. It is continually given off by the plant surface, especially by the leaves. This may easily be shown by placing a glass jar or other closed vessel over a growing plant. Drops of moisture will collect on the inner surface of the vessel as a result of transpiration. The familiar phenomenon of wilting is merely an indication that water is being lost somewhat more rapidly than it is absorbed from the soil by the roots. As a result of that process the soft, herbaceous parts of plants lose their crisp form and become soft and limp. If the wilting becomes excessive the plant is likely to die. When such a condition is reached, all the various functions of water in the plant and in the soil have ceased to be performed effectively.

The functions of water in plant growth: (1) It gives strength and form to the balloon-like cells of which plants are composed, by keeping them fully distended.

(2) It serves as food. Its elements, hydrogen and oxygen, are separated and built into the structure of the plant tissues ; and, in addition, water as such is an essential constituent of many plant materials. Water and its elements make up about fifty per cent. of the dry weight of plants and over ninety per cent. of the green weight. (3) Water dissolves plant-food in the soil and carries it into the plant. It also distributes the elaborated materials in the plant to the parts where they are used. (4) By evaporation the plant is protected somewhat against temperatures high enough to cause injury to its delicate tissues.

QUANTITY OF WATER USED BY PLANTS

The quantity of water which is used by plants for these purposes, and which the soil must supply, is very large, and varies considerably for different plants. By determining this total quantity and comparing it with the annual water supply either from rainfall or from irrigation, and also by determining the capacity of the soil to hold water for the use of plants and the possibility of increasing its conservation by appropriate methods of soil management, one may see to what extent larger crops are possible with the normal rainfall.

The most practicable method of determining the use of water by plants is to measure the amount evaporated from the plant surface during the entire period of growth and divide that by the amount of dry plant material produced. This shows the quantity of water used to produce a unit of plant material.

Many measurements of this sort have been made. The quantity of water used varies not only with the kind of plant, but also with the climate and in a minor way with many other conditions. The figures in the following

table represent the approximate range in the quantity of water used by a number of common crops under a climate ranging from moderately humid to semi-arid. There is also calculated the number of inches of rainfall that would be required in order to meet that need for water where large yields are produced. The yields stated indicate the general growth, but the weight of the entire top is used as the basis of the calculations.

TABLE 1.—QUANTITY OF WATER USED IN PRODUCING SOME COMMON CROPS

Crop.	Water requirement per pound of dry matter in tops (pounds).		Yield per acre.		Inches of rainfall* used in producing crops.	
	Minimum.	Maximum.	Bushels or tons.	Total dry matter.	Minimum.	Maximum.
			(Bushels)	(Pounds)		
Corn.......	250	375	100	10,000	11.0	16.5
Potatoes....	300	450	300	6,000	8.0	12.0
Peas	300	800	40	6,000	8.0	21.0
Wheat.....	250	500	40	6,500	7.0	14.0
Oats.......	400	600	70	7,000	12.0	18.5
			(Tons)			
Red Clover.	300	500	4	7,000	9.0	15.5
Alfalfa.....	600	1,000	6	10,000	26.0	45.0

* One acre of water one inch deep weighs approximately 113.5 tons.

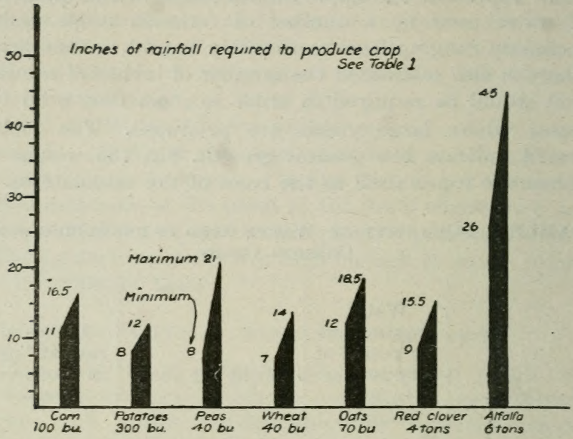

Fig. 53.—*Minimum and maximum rainfall used in producing some common crops.*

From Table 1 it is seen that the total quantity of water required for the plant to produce these large yields ranges from seven to forty-five inches. If the yields are divided by two, the amount produced will still be regarded as a fair yield ; and if the water used is calculated to the mean of the figures given, the actual quantity required by crops under average Eastern Canadian conditions will be found to range from five to eight inches of rainfall—except for alfalfa, which uses somewhat more than twice this quantity, or about eighteen inches. This large use of water by alfalfa is probably an important reason for its deep root system, designed to bring the plant in touch with the supply of moisture in the deep subsoil.

The depth of the root system and the thoroughness of

its distribution are important factors to be taken into account in controlling soil moisture for different crops.

ANNUAL PRECIPITATION

The annual precipitation in the form of rain and snow for the greater part of Eastern Canada is thirty to fifty inches. Limited areas have a smaller or a larger amount of precipitation, but these figures may be taken to fairly represent the soil water supply. Of this amount, eight to fourteen inches fall during the summer, at the rate of two or three inches a month. It is clear, therefore, that in Eastern Canada the rainfall is adequate for the production of large crop yields. The limiting factor, so far as water supply is concerned, is the capacity of the soil, either naturally or under the management of the farmer, to retain sufficient water within reach of the plant roots to carry them through the periods between rains.

MANNER IN WHICH WATER IS HELD IN THE SOIL.

It has been seen in an earlier lesson* in this series that the soil is normally a porous mass of rock and organic particles. The water derived from precipitation falls on the soil and sinks into the pore spaces. Each particle of the soil holds a film of water on its surface. This is due to the fact that the attraction of the soil particles at their immediate surface is great enough to separate the mass of water and retain some of it ; in other words, at the surface of the soil particles water is attracted more by the soil than by its own material. This attractive force is exerted for only a very short distance from the surface of the particles, and any film thicker than the range of that attraction is due to cohesion of the water. The extent of this cohesion is indicated by the thickness of the film of water at the instant when drops form.

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*No. 4

Since each particle of soil is covered by a film of water, the first factor in the determination of the quantity of water that a soil will retain is the extent of surface of the soil particles. The greater surface a soil has, the larger is the quantity of water it may be expected to hold.

The extent of surface in a mass of soil is determined by its fineness. The finer the soil, the larger is the extent of surface of the particles in a unit of mass. The extent of surface in a cubic foot of clean sea sand is less than one quarter of an acre. In a sandy loam soil it is one to two acres. In a loam or silt loam soil it is two to three acres. In a clay loam it is three to four acres, and in heavy clay it may be more than five acres. When free to do so, all particles of whatever size will hold the same thickness of water film on their surface. Consequently loam and clay soil holds much more water than does sand.

The surface of the soil particles is not the only factor that determines the retention of water. Due to internal physical forces the surface of water acts like a stretched membrane. It is in tension and always tends to assume the form that has the least surface. This is the reason why raindrops are spherical. When two soil particles each bearing a film of water are brought in contact the water films unite and form a waist, or connecting neck, at the point of contact. The film of water thickens in that part, and if one of the soil particles is in contact with a supply of water this neck will increase in diameter until it fills the angle between the particles, and the surface of the water becomes either plane or hemispherical. This is the phenomenon of capillarity. A concave, or dished, film of water exerts suction in its effort to straighten out. A convex, or bulging, form of water surface exerts pressure and will force water through the soil. Capillary, or film, water in the soil normally presents concave sur-

faces, which are increasingly dished as the water in the soil is reduced. If a series of wet particles are connected, the water will shift back and forth until all the curves of the water surfaces are the same ; which means that all have the same pull and consequently balance one another, and the water remains at rest. As the quantity of water in the soil is reduced, the connecting necks of water become successively smaller ; and finally they are broken, beginning where the soil particles are most widely separated.

In the soil there are many points of contact between the particles, and consequently many small necks of water. The smaller the particles, the more numerous are these points of contact. This is a further reason why fine-textured soils hold more water than do coarse-textured soils. Water held in this way is called *film*, or *capillary, water*.

Capillary water in soil

The quantity of capillary water held by different soils in good tilth, or physical condition, is shown in the following table :—

TABLE 2.—QUANTITY OF CAPILLARY WATER RETAINED BY DIFFERENT SOILS

Texture of Soil.	Weight per cubic foot (pounds).	Percentage of water retained.	Inches of water retained in three feet depth of soil.
Beach sand..........	110	4	2.5
Light sandy loam.....	100	10	5.8
Fine sandy loam	90	15	7.8
Loam...............	85	20	9.8
Silt loam............	80	25	11.5
Clay loam...........	75	35	15.0
Heavy clay..........	70	45	18.0
Muck................	15	200	17.0

In the last column of the table it is seen that a section of soil three feet in depth is able to hold as much water as falls in one to six months, depending on the physical properties of the soil.

Unavailable water in soil

Not all the water in the soil can be used by plants. Some is permanently unavailable to plants, due to the tenacity with which it is held by the soil. This occurs when the films on the soil particles become very thin. Therefore the quantity of unavailable water is proportioned to the fineness of the soil. It is greatest in clay soil, which has the greatest extent of internal surface, and it is least in clean sand and gravel.

Using the same soils as in Table 2, the approximate amount of unavailable and available water in a section three feet deep is shown in the following table :

TABLE 3.—AVAILABLE WATER RETAINED BY DIFFERENT SOILS

Texture of soil.	Weight per cubic foot (pounds).	Percentage of unavailable water.	Inches of unavailable water in three feet depth of soil.	Inches of available water in three feet depth of soil.
Beach sand..	110	1	0.6	1.9
Light sandy loam......	100	4	2.3	3.5
Fine sandy loam......	90	7	3.6	4.2
Loam.......	85	12	5.8	4.0
Silt loam....	80	15	6.0	5.5
Clay loam...	75	20	8.6	6.4
Heavy clay..	70	30	12.0	6.0
Muck.......	15	100	8.7	8.3

It is evident from Table 3 that any except the very lightest sand soils are able to hold enough available water to largely meet the requirements of crops for moisture and to bridge over the periods between rains. It is to be remembered that to these quantities is added the rainfall during the growing period, amounting usually to four to ten inches. The soils under consideration are supposed to be in perfect physical condition to a depth of three feet. It has been clearly shown in investigations in Western States that plants can utilize water stored at a much greater depth than three feet,

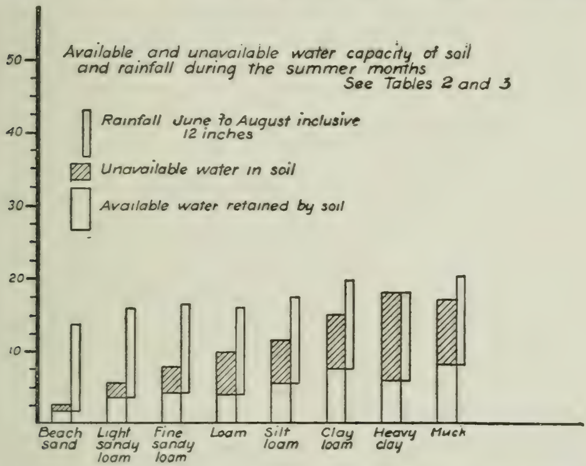

Fig. 54.—*Diagram representing the amount of total, unavailable, and available water retained by a three-foot section of soils of different texture. To the available water retained is added the average rainfall within the crop-growing season. This gives the total amount of water that can be made available to growing crops.*

but this depth may be taken as the ideal for Eastern conditions. There may be a water-table or other available forms of water below three feet in depth that may be drawn upon to replenish moisture lost from the upper part of the soil sections.

Control of water capacity of the soil

Insuring absorption of precipitation

The first problem of the farmer is, how to put his soil in condition to absorb water as it comes in the form of rain or snow. If the surface is very compact and sloping the water may run off over the surface before it can absorbed. Especially is the maintenance of a loose, open surface soil desirable during the summer, when the rainfall is likely to come in heavy, dashing showers and when the topsoil is dry. If the soil is fine and compact, the air is trapped and water can find admission only as the air slowly escapes—much as a bottle can be filled only as the air escapes. The flow of the water over the surface may also cause serious erosion.

Increasing retentive capacity of the soil

If the capacity of the soil to absorb water is reduced by its physical condition, it is the function of the farmer to practise such methods of tillage and management as will improve that condition. The soils that naturally remain in the best physical condition are the silt and the sandy soils ; the loam and the clay soils are more likely to get into bad condition. There are two extremes to be guarded against : one is the very open condition typified by coarse sand and gravel ; the other is the very compact, dense condition represented by puddled clay.

Management of sand soil.—In coarse sand soil the

surface of the particles is small in extent, the points of contact between the particles are few in number, and the individual spaces are relatively large. Such a soil has a low water capacity and is so well ventilated that organic matter rapidly decays. Since the particles of soil cannot be pulverized, the desired change must be accomplished in another way. Several courses are open.

First, such a soil should be kept as compact as possible. It is better ploughed in fall than in spring, in order that excess water of the winter may bring the particles close together. If humus is not being applied, shallow ploughing is better than deep ploughing, since the operation of ploughing loosens the soil. The roller should be used freely. Even sand is made up of particles of different sizes, and if it is ploughed when a little wet it may be partially puddled, which is a favourable condition in soil inclined to be very loose. In that case the small particles are worked into the larger spaces and reduce their average size to a more effective diameter. This increases the quantity of water retained.

Second, material may be added to the soil to partially fill the large spaces and increase the number of points of contact. The most desirable material for this purpose is humus—decayed organic matter. Clay would have a similar effect, but its use is not so practicable and it also introduces some disadvantages. Increase in the stock of humus and its deep incorporation is therefore effective to increase the water capacity of light sand soil, and, when coupled with deep ploughing and the use of compacting implements, the best results are attained. The introduction of the humus more than offsets the disadvantage of deep ploughing.

Management of clay and puddled soils.—In very

fine-textured soils, such as clay, and in loams and sandy loams that are in a puddled condition, the pores are so small in size, and may also be so small in total volume, that the soil has a very low capacity to hold available

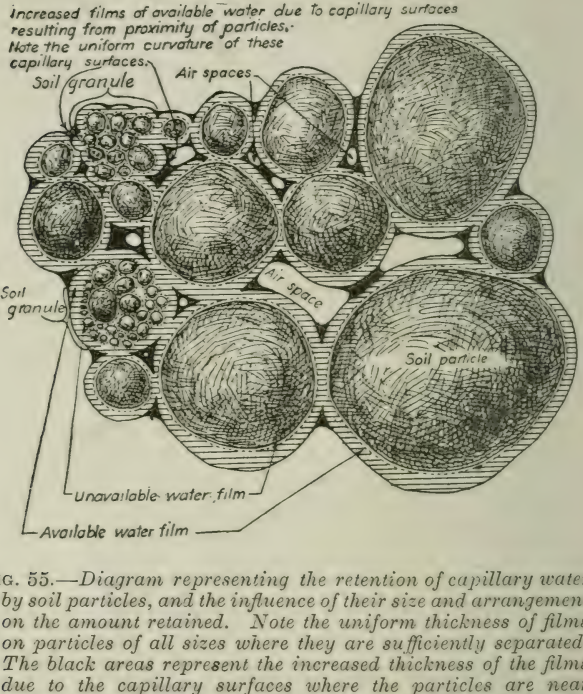

FIG. 55.—*Diagram representing the retention of capillary water by soil particles, and the influence of their size and arrangement on the amount retained. Note the uniform thickness of films on particles of all sizes where they are sufficiently separated. The black areas represent the increased thickness of the films due to the capillary surfaces where the particles are near enough for the water films to join. On each particle is a thin film of water unavailable to plants. Water in the interior of granules is largely unavailable.*

water. Clay soil is especially prone to be in such a compact condition, and great care must be exercised in its management.

It is especially important that these soils be loose and granular. The finer the soil, the greater should be the effort to put it in a granular condition. In coarse sand soils, the individual particles may rest close together and yet the spaces be too large to be fully effective. On the other hand, in fine clay, if it is pulverized so that the individual particles rest close together, the spaces are so small that they incline to remain full of water, thus cutting off ventilation and preventing the penetration of roots. This condition is further aggravated by the ease with which such a soil is puddled, thereby further reducing the size of the spaces. The water films do not have opportunity to attain their maximum thickness, and the water that is held is so close to the surface of the soil particles that it is largely unavailable to the roots of plants.

The correction for this consists in creating a granular, or flocculated, condition of the soil, so that a number of small particles act together like a single larger particle. *Granulation is important.* The most effective size of granule ranges from the size of corn kernels to that of timothy seed. Inevitably there will be considerable finer material, so that the mass will have a loamy structure.

By loosening the soil, opportunity is given for the maximum thickness of films and the largest proportion of available water.

In a soil that is too fine and compact, the development of the granular condition is greatly assisted by good cultural methods applied at the time when the soil is most friable by having the right moisture content.

Fundamental to all of these is good drainage. The surface soil can be improved to a large extent by tillage coupled with moderate drainage; but the subsoil, to the ideal depth of three feet or more, can be improved only by natural processes, at the basis of which is such a degree of drainage as will permit the removal of any free water so that drying and shrinkage is possible. This change in the physical condition of the soil is the basis of the statement frequently made, that drainage increases the available water capacity of the soil. In addition it admits air, which permits plant roots and various forms of animal life, such as earthworms, to penetrate deep into the soil, and these further aid in the process of granulation.

The use of lime where it is deficient, and the generous introduction of humus, are also effective aids to granulation; and a further benefit from the presence of humus is its own large capacity to hold water, as is illustrated by muck soil.

When clay or other puddled soil is ploughed, it is likely to break up into large lumps. This is a form of granulation, but, as in sand and gravel, the lumps are too large and must be reduced in size by pulverizing.

Between these two extremes of soils—those that are too loose and those that are too compact to have the maximum ability to hold available water—is every gradation of condition. The intermediate soils, such as sandy loams, loams, and silt loams, are easier to manipulate and are adapted to the widest range of crops and farm practices. The farmer must always use his judgment as to the particular treatment his soil needs, having in mind its present condition, the desired change, and the attendant seasonal conditions and crop requirements.

Free, or hydrostatic water

Film water is the only form of soil moisture used directly by crops. When the films have reached the maximum thickness, the soil has all the water that it can retain and this quantity will be permanently held in the soil. It cannot be removed by drainage. If, however, the large spaces are filled with water beyond the range of the films, this added water is not held by capillary force and is free to pass downward under the influence of gravity unless the lower part of the soil is impervious. This free water is termed hydrostatic water, and is the part of the soil moisture that is removed by drainage. The height to which the large spaces are filled with water is called the water-table ; its presence excludes air, and thereby repels the growth of roots of all the common crops that are not adapted to grow in saturated soil. Drainage aims to lower the water-table so as to give a suitable root zone, which should be at least three feet in depth.

LOSS OF WATER FROM SOIL

It is well known that crops frequently suffer from the lack of available water. From the above discussion it is evident that the difficulty is not with the water supply relative to the quantity used by crops. Nor is it due to the complete inability of the soil to retain enough of the precipitation to meet the needs of plants. It must therefore be due either to the fact that the soil is not in condition to absorb the precipitation, or to loss after the water has been absorbed. We have pointed out the ways in which the capacity of the soil to absorb and hold water in available form may be increased. It now remains to consider the ways in which water is lost from the soil.

It is evident from what has been said that when the soil has taken on the maximum films of water, any excess is properly permitted to drain away out of the root zone.

Growth of weeds

Film water can be lost only by evaporation. Its removal by evaporation from the leaves of the crop is essential and must be provided for. Its waste by evaporation from the leaves of weed plants is to be avoided by their destruction. The destruction of weeds is one important reason for tillage. The larger the weed plant and the deeper its root system relative to the regular crop, the more injurious is its growth likely to be by the exhaustion of the water supply. Since the water supply also measures the solution and transfer of plant-food from the soil to the plant, it is evident that weeds interfere with the nutrition of the crop as well as with its water supply. By expanding the evaporating surface, weed plants greatly increase the loss over what it would be directly from the soil.

Evaporation from the soil

The phenomenon of the evaporation of water from a moist soil is a common one. If a soil were kept well moist throughout the year, the total amount of water that would evaporate would be sixty or seventy inches, which is more than would evaporate from a water surface because the wet area is increased by the uneven surface of the soil. This illustrates the large possible waste of water if some provision is not made for its conservation. Under average field conditions, the loss of water by evaporation is not so large as the figures just given ; but it does account for the difference between the fifteen or twenty inches of water that plants may use and the three, four,

or five inches that they actually do use in their growth. One of the big problems of the farmer is to prevent this useless and expensive loss of water by evaporation from the soil.

Mechanism of evaporation

In the process of evaporation, very small particles of water become detached from the main mass and float off in the atmosphere. They are detached by their vigorous vibration at the surface of the water, which is increased as the temperature increases. Consequently, if other conditions are equal, the warmer the water the more rapid is evaporation.

The detached particles of water move about promiscuously in all directions in the atmosphere and are said to diffuse through the atmosphere. Some of them find their way back to the surface of the soil. If the soil were absolutely dry, the contact of these moisture particles with it would make its surface somewhat moist. All objects, including the dusty-dry soil, carry a certain quantity of such *moisture of condensation*, termed *hygroscopic moisture.* The quantity of water taken up by a soil in this way is never enough to support the growth of crops, although it probably is helpful to the growth of bacteria, which are exceedingly small plants. From the last statement it is evident that the common belief that a compacted soil which becomes moist derives its moisture from the air, is wrong, and that this fact must be accounted for in another way. The moisture that appears in a footprint in a dry soil comes from below, not from the air, in accordance with laws that will be further explained in this lesson.

If the particles of water that are detached from the moist soil are free to move away in the atmosphere, the

loss will continue as long as moisture is available. The warmer and drier the air, the more rapid is the loss of water. Winds that hasten the movement of the particles of moisture and bring a new supply of dry air in contact with the moist soil greatly increase the loss. This is the basis of the common statement that winds have a very drying effect.

On the other hand, if the volume of air in contact with the soil is limited and relatively small—say a layer a few inches, or perhaps a few feet, in thickness—there will come a time when no more particles of water can be taken up. Physicists explain this stage as due to the fact that as many particles drop back into the liquid as pass out into the air. An equilibrium is established and the atmosphere is saturated ; hence loss of water stops. That is what occurs when a lid is placed over a pail of water or when a box is turned over a block of moist soil.

Mulches

There are various ways of covering a soil in order to stop loss of water by evaporation. One method is to cover the soil with boards. Stones serve the same purpose, and where other means were not practicable stones have sometimes been hauled on the soil to form such a cover. Soils that are very stony at the top have been observed to hold moisture well, and the removal of the stones has resulted in less growth of crops. Another method is to cover the ground with a mulch of straw or leaves. There is a method of growing potatoes by which the tubers are placed on the surface of the ground and deeply covered with straw. The potatoes grow, and may reach a satisfactory maturity. The straw holds the moisture in the soil to the very surface, so that the roots may develop and find their way

into the soil for sustenance. A layer of coarse sand or gravel serves the same purpose, and even a very dry layer of finely pulverised soil may be placed on a moist soil and will prevent the evaporation of moisture in the same way because it forms a cover.

However, all these methods of covering the soil in order to save water are impracticable except on a very small scale. For the average farm it is necessary to make the cover out of the natural soil. It is well known that such a cover, consisting of a layer of fine, dry soil, is effective to prevent evaporation. It is called a dust mulch, dust blanket, soil mulch, or dust cover.

Simple rules can be given for the general management of the soil in order to secure and maintain a mulch. These rules usually involve the frequent stirring of the topsoil as soon after a rain as is possible without puddling the soil. The stirring should be repeated as often as the topsoil has become moist and caked; this condition indicates that it has largely lost its efficiency as a mulch.

Management of the dust mulch.—In order to understand the reason for the effective management of a mulch, as well as to be best able to decide the particular treatment to be given, it is essential to understand the principles involved. Throughout Eastern Canada, where there is a generous rainfall, the mulch must be made from the moist soil.

Dry soil acts as a mulch because when dry it tends to remain so and does not readily taken on a new water film. There are in every soil organic substances of a fatty or greasy nature, and when once the soil becomes dry these form a coating on the particles which offers some resistance to the absorption of water. Further, when a soil is dry, moisture creeps over its surface very slowly, especially if the adjacent soil is only moderately

moist. Any treatment that causes the topsoil to become dry forms of it a mulch. It is not even necessary that the mulch be loose if only it is dry, but in practice looseness is necessary in order to quickly secure a dry condition.

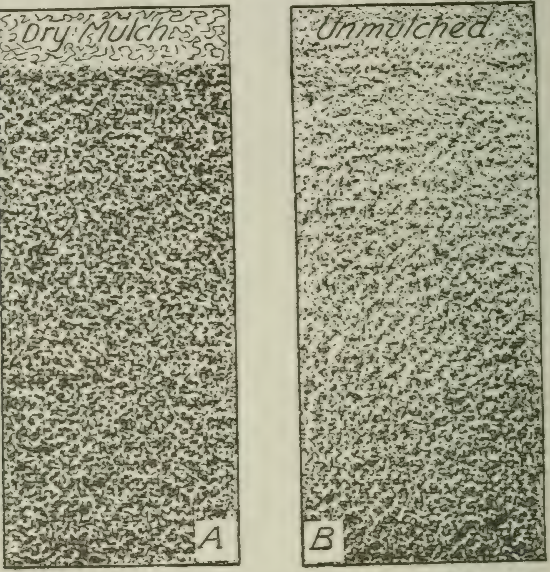

FIG. 56.—*Diagram representing the relative distribution of moisture in two sections of soil receiving different treatment: A, covered by dust mulch, moisture is abundant up to the under surface of the mulch; B, without mulch, soil is dry to a considerable depth.*

In the field a mulch is naturally formed in the following way: As soon as rain ceases and the atmosphere

becomes somewhat dry, evaporation begins from the surface of the wet soil. As evaporation proceeds and the top soil becomes less moist than the soil below, moisture moves up from the adjacent layer to partially replenish the loss. If, however, evaporation is more rapid than the rate of movement of water into the surface inch or two of soil, that soil will gradually become dry. The drier it becomes, the slower is the movement upward from below ; so that the more rapidly the soil becomes dry, the more rapidly is the mulch developed by which the water in the underlying soil is protected. If the atmosphere is very dry and warm, the mulch may quickly form naturally without the loss of water from more than a few inches of the top soil. This is what happens after an application of water to the soil in arid regions. In humid regions such as New York, however, the atmospheric conditions much of the time, and especially just after a rain, are favourable for slow evaporation which may very slightly exceed the movement from below. Hence the top soil will remain moist for a long time—several days or weeks—and the loss of water may extend several feet into the soil. Eventually a very deep mulch would be formed, but the loss of water in the process is very great. Another rain may come in the meantime so that the soil is kept almost continuously in condition for the loss of water. Further, the moisture condition of the atmosphere varies. One day of a very drying atmosphere may be followed by a damp, muggy day in which the movement of water from the subsoil almost or quite equals the loss of the two days. This contributes to the waste of water.

By cultivating the top layer of soil its structure is loosened so that evaporation from that part is hastened. The loosening also reduces its contact with the moist

soil below, so that less moisture is absorbed. Hence cultivation greatly promotes the formation of a mulch.

It should be understood that the absorption of moisture by the mulch never entirely ceases, although it becomes very small. Even after the top soil is approximately dry, a period of very moist atmosphere, such as accompanies foggy or very cloudy weather, may permit the absorption of moisture from the subsoil to partially destroy the mulch, so that if a period of drying weather follows, the total loss of water may be considerable.

From these facts it is evident (1) that tillage usually aids in the formation of a mulch; (2) that the mulch should be as shallow as is practicable in order that the least amount of water may be lost in its formation; and (3) that when once the mulch is dry further tillage is of no advantage as long as it remains essentially dry, but should the mulch become moist and form a crust further tillage is beneficial.

Sandy soils are easier to mulch and to maintain in a mulched condition than are clay soils, because the drying is more rapid and the absorption from below is slower. Normally, if evaporation continues at the surface of the soil, moisture will be lost to a depth of two or three feet as a result of the process of equalization by capillary movement from below. In those soils that crack seriously the loss from the subsoil is increased by evaporation into the air in these cracks, from which the moisture rapidly diffuses or is sucked out by winds passing over the surface. Clay and muck soils are most inclined to form large cracks, and it is especially important to keep these cracks sifted full of dry soil in order to reduce the loss of water from the subsoil.

Depth of soil mulch.—The use of a soil mulch is practicable for all tilled crops. The depth of mulch that is

adequate to prevent a large part of the loss by evaporation may be one half-inch to two or three inches. A half, or even a quarter, of an inch of fine, dry soil will reduce evaporation to seventy-five to ninety per cent. of the loss without a mulch. As indicated above, the climatic conditions have much to do with the efficiency of a mulch, and in general a mulch is not so effective in the humid climate of the Eastern States as in the arid climate of the Western States. It has, however, been demonstrated many times that the saving of water by thorough mulching may make the difference between a full crop of corn and a half crop or a complete failure. In orchard management, tillage, with the consequent mulching, has much to do with the better growth of fruit, as compared with grass crops. That mulching is an effective means to prevent loss of soil moisture, and that sufficient water can be stored in the soil to meet the needs of crops, is abundantly shown by experience in the arid and semi-arid sections of the country. Where water is available for irrigation only in the winter, as in parts of the North-West, full crops are produced without any rainfall or application of water during the crop season. On the eastern slope of the Rocky Mountains, where the rainfall in one season is often not adequate to produce a good crop and irrigation is not practised, the rainfall of two seasons is stored in the soil and held by a mulch, to be used in producing a crop in alternate years.

In sandy loam or other soils where a good tilth is easily maintained, a mulch of a half-inch to an inch in depth is entirely practicable. Implements having many small shovels or an equipment of horizontal blades are essential in order to do good work of this sort. In clay soil inclined to be cloddy, a somewhat deeper mulch, of one

and one-half to three inches, must usually be maintained in order to get sufficient fine earth to be effective. About two inches is the depth found to give best results on such soil. Clods a half-inch or more in diameter do not form an effective mulch unless it is two or three inches thick.

Distribution of soil moisture under a mulch.—Where no mulch is established the soil is likely to be relatively dry for a considerable depth. Plant roots do not find favourable conditions to get either moisture or plant-food in that part of the soil section, and a large part of it is ineffective. On the other hand, in a well-mulched soil abundant moisture occurs, up to the very base of the mulch, and roots are able to utilize almost the entire soil section.

Mulching crops that are not tilled.—Many crops are not tilled so that the dust mulch is not applicable. The treatment here must be even more deep-seated. It is especially important that such plants be able to

FIG. 57.—*Making a dry mulch by the use of a spring-tooth harrow.*

establish and maintain their roots deep in the soil. Thorough drainage is therefore very essential. In arid sections grain crops are sometimes cultivated. Provided the cultivation begins when the plants are very small, it may be continued without serious damage until the heads begin to form.

There is opportunity for benefit by the use of available manure as a top-dressing and mulch on the grain and the new grass land. Especially is this desirable when grain is used as a nurse crop for grass. When the nurse crop is removed in midsummer, the grass plants are weak and the soil is exposed to rapid drying, both of which conditions are hard on the grass plant. The manure forms a mulch as well as affords a generous food supply; and the practice, which is becoming common in Canada, is shown to give good return in the succeeding crops of hay and grain. After a crop has reached the size at which it effectively shades the ground and holds the air in place near the soil so that it becomes saturated with moisture, the loss by evaporation from the soil is much reduced, except when heavy winds occur that suck out this moist air and replace it with dry air—which process cannot be controlled to any extent. Windbreaks afford some protection.

MOVEMENT OF WATER IN THE SOIL

It has been pointed out that the soil water on which plants depend is held in the form of films on the soil particles, and that these films exist in a state of tension. The tension is due to the curvature of the water surfaces in the necks between the soil particles. When a moist soil has stood for a long time without any loss, the moisture should be uniformly distributed over the particles throughout the mass, except that the films

are thicker at the bottom than at the top of the section, due to the pull of gravity on the water. This modifies, but does not overcome, the capillary, or curvature, pull. If a sand and a clay soil are in contact, each will take the same thickness of film on its surface. The amount of moisture required for the same thickness of film on two soils of different fineness is called the *moisture equivalent.* Two soils of different texture have come to their moisture equivalent when the same plant wilts on each soil under the same atmospheric conditions. Two soils having the same thickness of film, whether that thickness be great or small, will appear equally moist, although in each unit volume one soil may actually hold twice as much water as the other.

Fig. 58.—*Diagram illustrating unequal distribution of capillary water in a mass of soil. Where the film is thick* (*y*) *the curves are flat and exert a small pull, as at d, e, and f. Where the films are thin* (*x*) *the surface curves form acute angles and therefore exert a large pull, as indicated by the length of the arrows at a, b, and c. The direction of movement of water is indicated by the feathered arrows.*

If for any reason the films of water are thinner in one part of the soil mass than in the adjacent soil, the greater curvature of the surface of the films in that part will draw in water from the wetter part. This adjustment will take place for an indifferent distance in all directions. For example, if water evaporates at the

surface of the soil, the moisture would be drawn up from the subsoil,. As plant roots use the water in contact with their surfaces, water moves in—drawn by capillarity—from the more remote, but wetter, particles. It is a general principle that water in the soil moves from the place where the films are thick to the place where they are thin. Any change in the structure of a moist soil that alters the relative thickness of the films in the different parts of the mass will start movement of the moisture to bring about equilibrium.

Some treatments that influence the capillary movement of moisture

Use is made of this principle of capillary, or film, movement of water. For example, when the soil is relatively dry and a rain occurs, capillarity helps to pull the water into the soil. As the upper soil dries out, capillarity returns water to the surface. It draws moisture to meet the roots advancing through the soil. When the farmer plants very small seeds on the surface of a dry soil, it is customary to use a roller, which packs the top soil, thereby increasing its capillary pull so that moisture is drawn up from below to germinate the seed. When very dry land is ploughed it is sometimes packed in order to *draw moisture* from the subsoil. When the immediate surface is left loose the operation is called sub-surface packing, for which purpose special implements have been devised. In many ways the farmer makes use of the principle of capillary movement and many of his tillage operations are designed to effect capillarity. It is involved in the production of a mulch, as explained above.

Sometimes the addition of a small quantity of water to the soil may prove harmful because of this film

movement. As has been pointed out, when the soil is relatively dry, movement is very slow. If a small quantity of water is added, either by a shower of rain or by artificial application, it is sufficient to re establish rapid capillary movement without causing deeper penetration. Evaporation is hastened. All the water applied is lost, and before the process ceases further quantities of water will be removed, small rains are therefore usually injurious, for they add nothing permanent to the soil and necessitate the re-establishment of the mulch. The common practice of adding a little water to lawns is to be condemned for this reason. When an application is made it should be sufficient to penetrate considerably below the mulch layer. This usually requires one or two inches of water.

Rate of capillary movement

While differences in the distribution of water in a soil will adjust themselves over considerable distances, the rate of movement may be so slow as to make the process of little value. The particles of water must move through the thin films. When the films are reduced so that they are very thin, the friction against the surface of the soil particles is so great that it stops movement for all practical purposes. This is why plants wilt in soil that appears moist. When the films are thick the outer particles of water are quite free to move and adjustment is rapid. In a puddled clay soil that may be wet to the point of stickiness, the water moves with extreme difficulty because all the films are very thin, due to the extreme fineness of the particles and the very small size of the spaces. In a granulated soil the films in the large spaces are able to become thick and thereby movement is much freer. Because of these

extreme possible differences, the tilth of clay soil is particularly important and puddling is especially to be avoided.

SOME PRACTICES THAT AFFECT SOIL MOISTURE

A few common farm practices may be discussed in their relation to the conservation of soil moisture

Ridge versus level culture.—For the conservation of soil moisture, level cultivation is now universally recognised as the best practice. Ridges increase the surface exposed to evaporation, and they also increase the difficulty of maintaining a good mulch. Even potatoes are now generally cultivated level, and with better results in the long run than follows ridge culture.

Early spring ploughing.—In spring the soil is generally saturated with capillary water, if not also with free, or hydrostatic, water. The atmosphere is moist, although

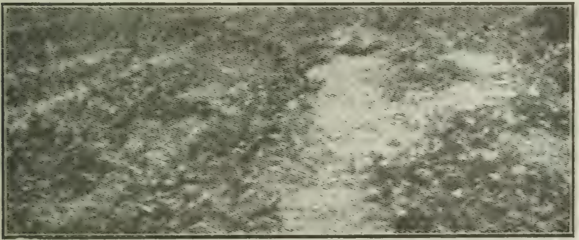

FIG. 59.—*A mulch of straw, such as is frequently used on land devoted to small fruits.*

dry enough to permit fairly rapid evaporation ; and after the soil is dry enough to till, any delay may occasion the loss of an inch or more of water each week. This

quantity would make the difference between a large and a small crop. Land should be ploughed as early in spring as possible, and if it cannot be ploughed it is sometimes practicable to partially mulch the surface by discing or harrowing.

Early summer and fall ploughing.—In the semi-arid regions where both the summer and the winter rainfall must be stored, ploughing as soon as the crop has been removed in the early summer and fall is especially important. But in New York, where the soil usually becomes saturated in the winter irrespective of past treatment, early fall ploughing is not important; in fact, late fall ploughing is preferable because of its relation to soil organisms and the physical condition of the soil.

Where a fall crop is to be planted, ploughing as soon as the previous crop is removed, if accompanied by cultivation, may save sufficient moisture to make much difference in the starting of the succeeding crop.

Ploughing under green-manure crops.—The drying effect of crops has been pointed out. If a green-manure crop is allowed to stand until late in the spring, it may deplete the soil moisture to such an extent that the succeeding crop will have difficulty in starting, especially if the season be a little dry. After a green-manure crop has commenced to flower, nothing is usually gained from further growth.

SELECTION OF TILLAGE IMPLEMENTS

The selection of tillage implements for the control of soil moisture must be guided by the change in soil structure that is to be made. A large variety of implements are available, all of which may be grouped into a few fundamental types. The two main groups of these are (a) compacters and (b) implements that loosen the

soil. Of the latter group ploughs operate to the greatest depth. Subsoiling is seldom advisable. Deeper ploughing is generally advisable, especially if it is accompanied by

FIG. 60.—*A natural mulch of stone.*

the addition of organic matter. Tillage implements are usually selected with reference to the crop and the condition of the soil, in addition to their effect in keeping the surface level.

CONCLUSIONS

It is clear that for the great majority of Eastern Canada soils and crops, there is sufficient water supply if it is effectively managed. This is possible to a much larger extent than is now realized. Our climate is subject to rather extended periods of dry weather, as well as of wet weather. The wet periods can be largely offset by drainage. Therefore it is the part of wisdom to manage the soil as if each season were more dry than the normal.

If moisture is supplied, growing conditions are better in dry seasons than in wet, dark seasons. In that direction is the largest opportunity for the capable farmer to get results. Irrigation has some place as a supplement to the natural rainfall and storage capacity of some soils, but usually only after better methods of control of soil moisture have proved their inefficiency.

DISCUSSION PAPER

The Discussion Paper is planned to help the student by drawing his attention to the important points of the subject he is studying. It is intended to develop thought and self expression of his own ideas. Each discussion paper, when answered and returned, is carefully read by the staff of the Department of Agriculture and a personal statement is given in connection with any question that the reader thinks the student has not fully understood. The student is invited to ask any questions that will help to give him a more complete understanding of the course.

GENERAL INSTRUCTIONS

1. Always express your ideas in your own words.
2. Finish one paper at a time.
3. See that the subject is placed at the top of the first page of each paper answered.
4. Do not forget to write your NAME, NUMBER, and COMPLETE ADDRESS, on each set of answers.
5. Number each question, and also each sheet, and pin them together in their right order.
6. Send in each paper as soon as complete.

QUESTIONS

1. Describe four important functions of water in plants.
2. Describe the symptoms of plants deprived of sufficient water for normal growth. What happens to a plant suddenly deprived of water ?
3. In what different ways is water retained in the soil ? Mention the water supply that is available to the plant.
4. Can the capacity of a soil to retain moisture be increased ? How ?
5. In what ways may soil water that should be available for a crop be lost ?
6. What are the advantages to be gained by applying a mulch ? Discuss the relative merits of the different mulches described in the text.
7. Can soil moisture be conserved as easily in a climate with an annual rainfall of 15 inches as in one with a rainfall of 45 inches. Why ?
8. Describe the various movements of water in a soil. Can they be controlled ?
9. Will a ridged surface give off more water by evaporation than a smooth suıface ? Why ?
10. Is it good practice to always prepare for a season drier than normal ? Why ?